# 2017 GNU Hackers Meeting

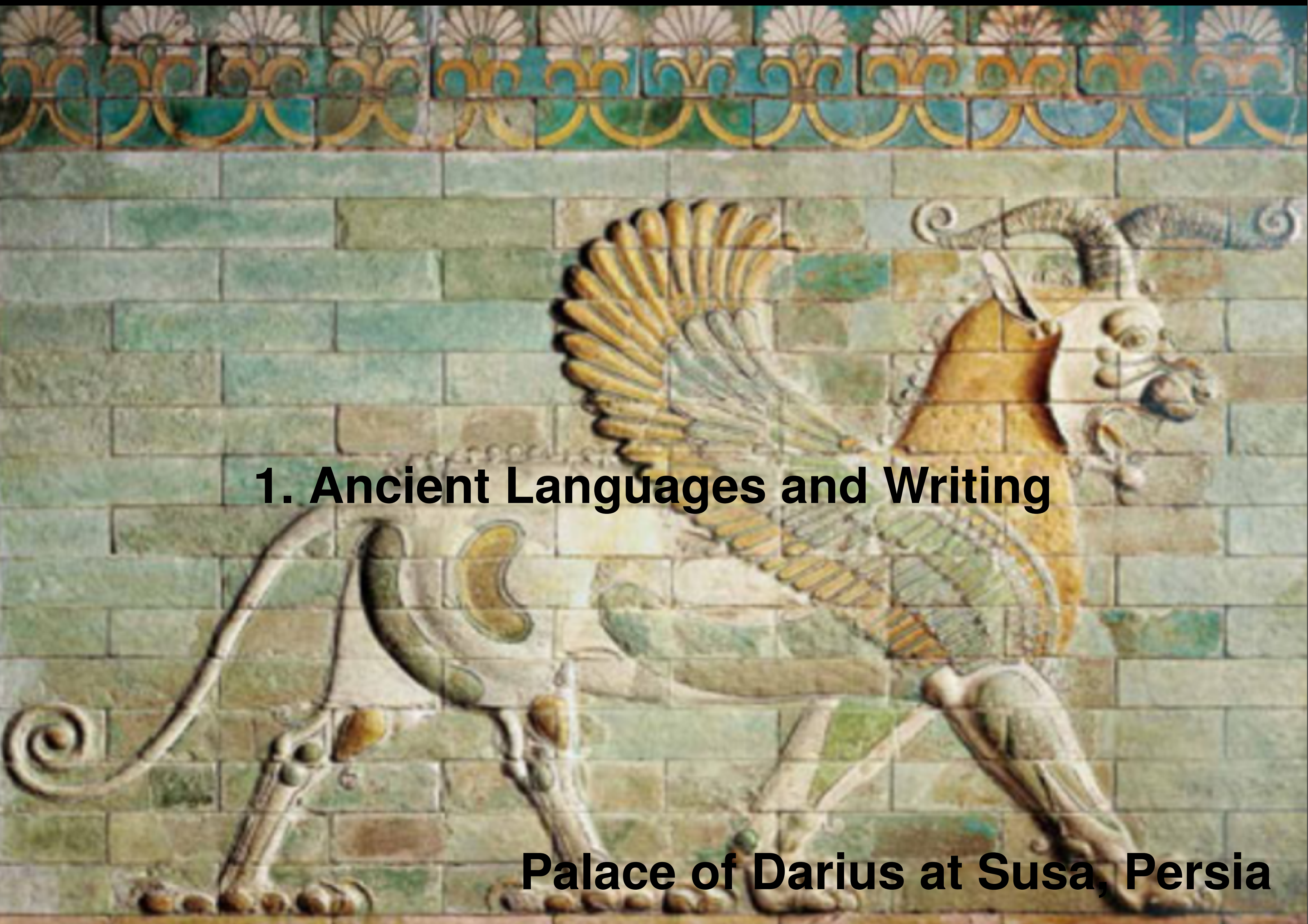
## The GNU Behistun Package

1. Ancient Languages and Writing
2. Disaster Preparedness and Mitigation
3. Seismic Subsurface Mapping

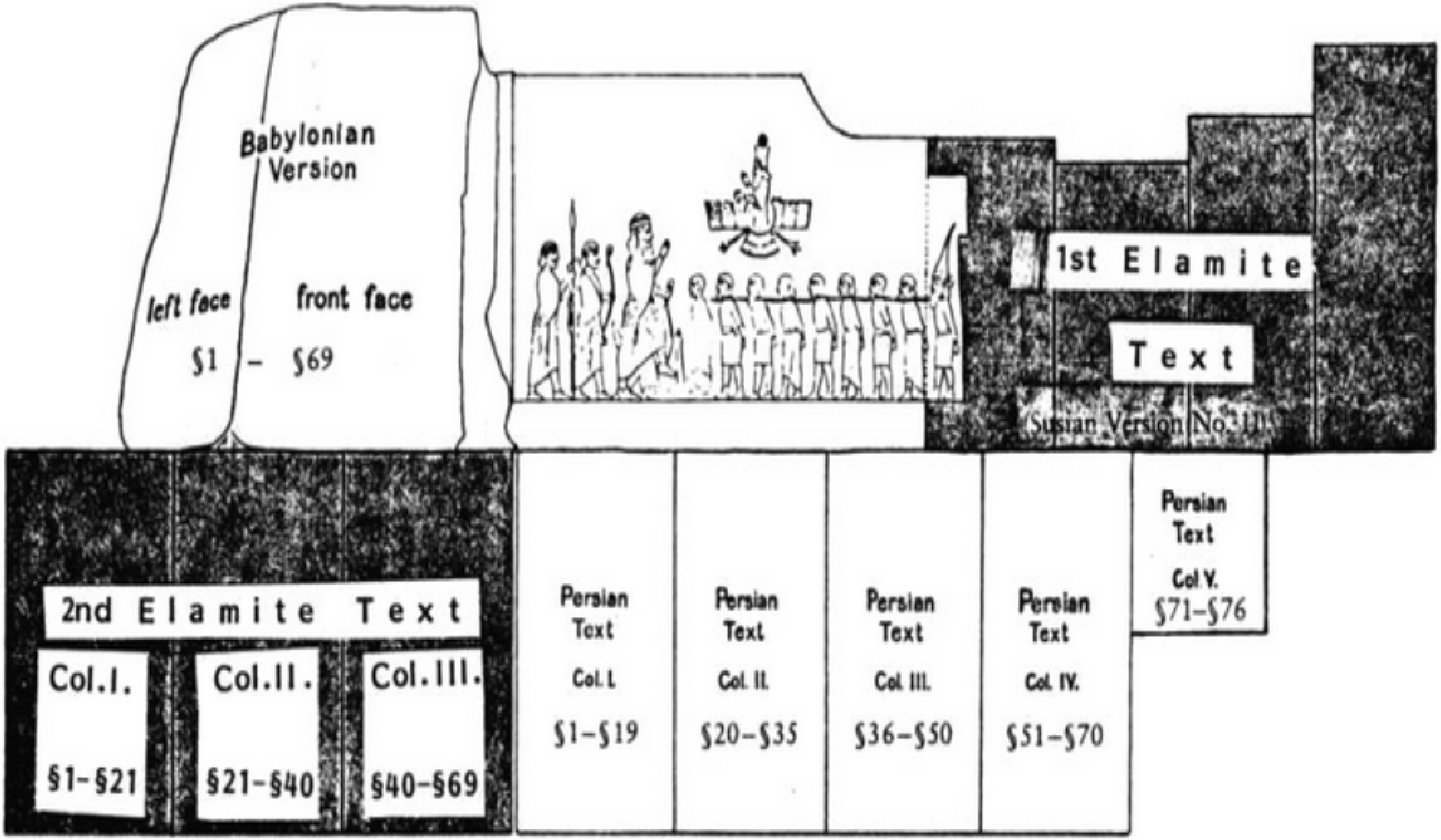
Speaker: Christopher Dimech

Palace of Darius at Susa, Persia

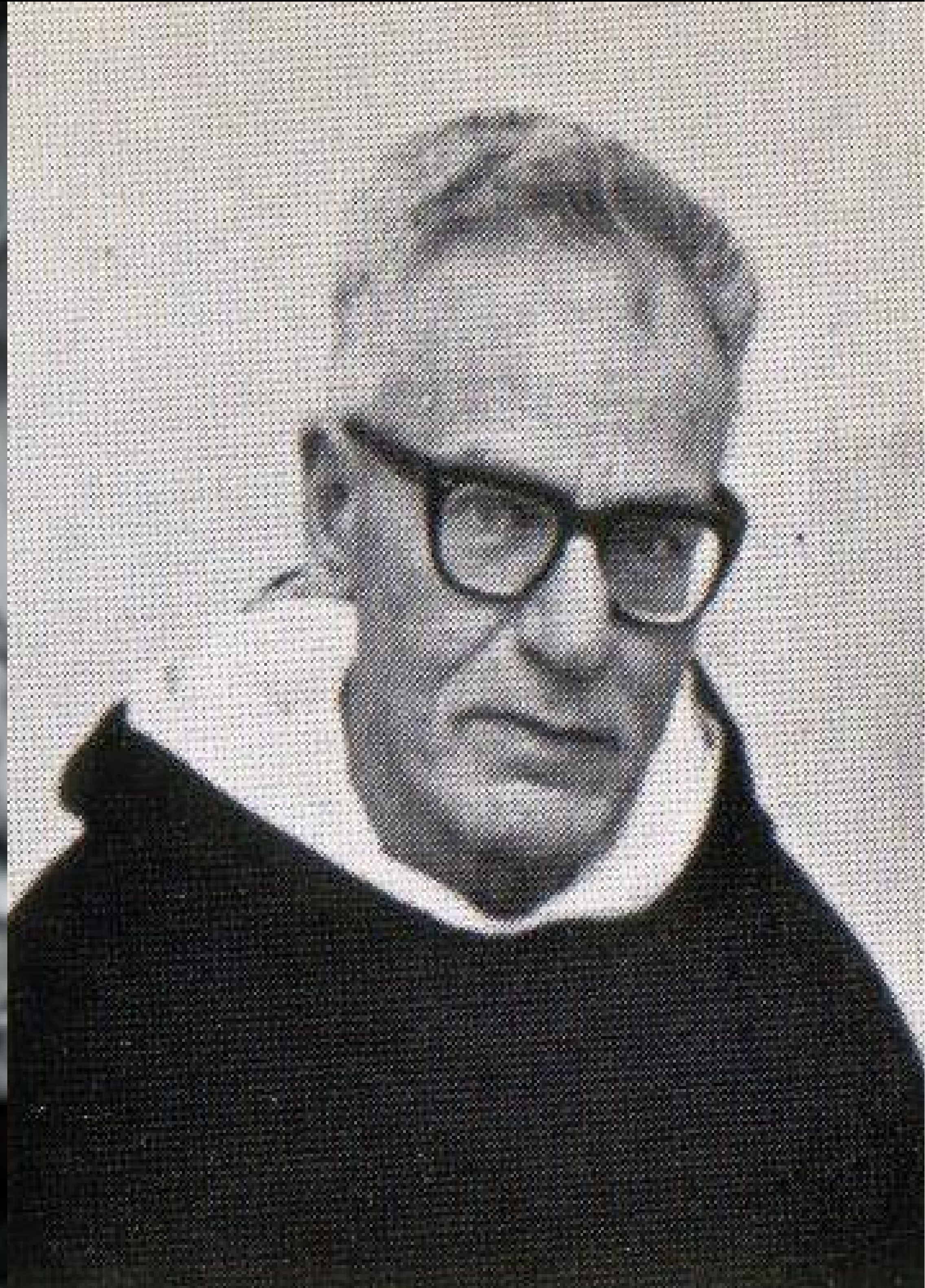
# 1. Ancient Languages and Writing



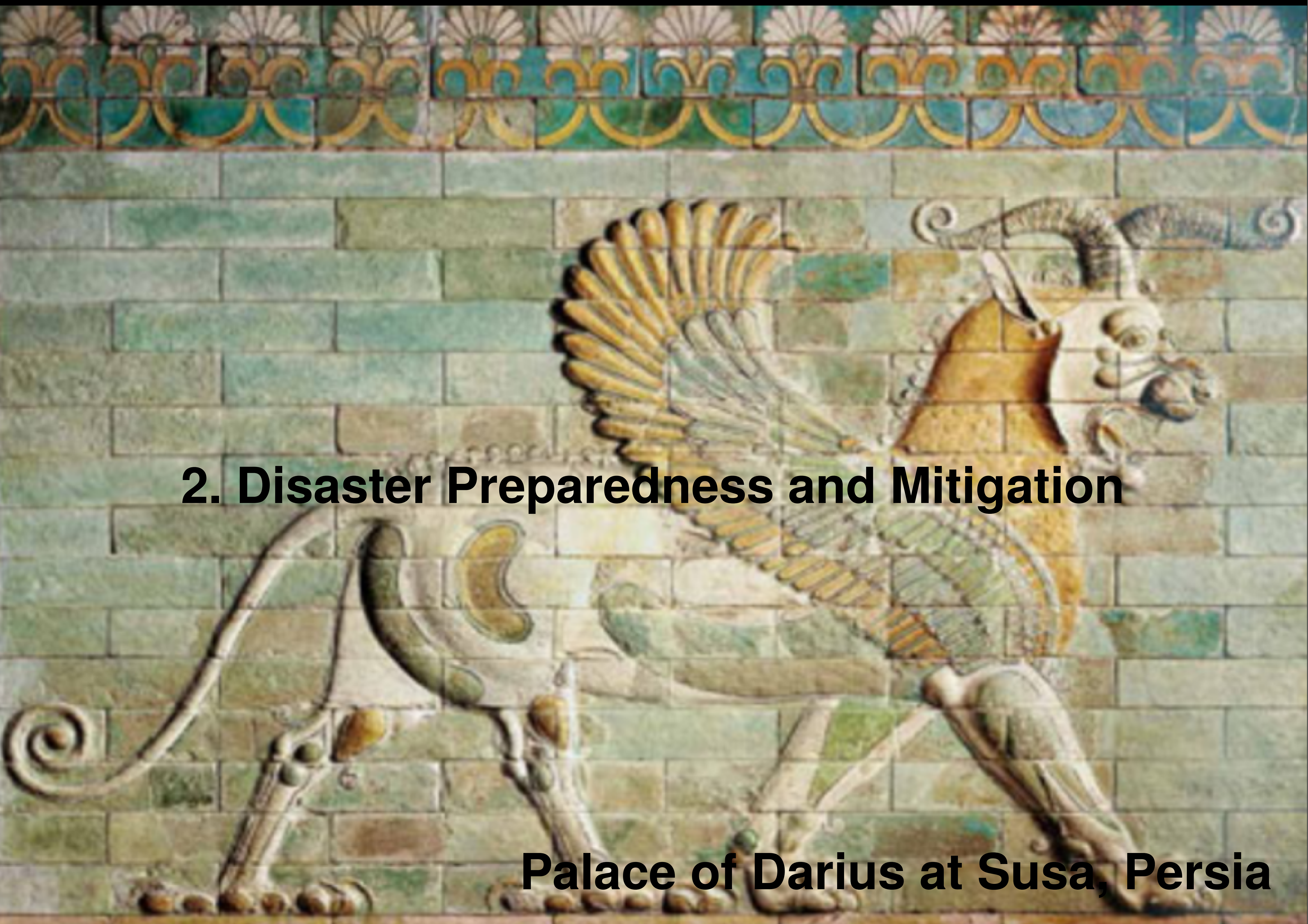
Palace of Darius at Susa, Persia




The positions of the Old Persian, Elamite, and Babylonian versions of the major trilingual inscription DB on the rock at Bīsotūn. Source: King and Thompson, pl. VI; corrected by Borger, fig. 2; adapted by R. Schmitt



## 2. Disaster Preparedness and Mitigation



Palace of Darius at Susa, Persia

2011. The Fukushima Daiichi Nuclear Disaster

2011. The Fukushima Daiichi Nuclear Disaster

**2010, Deepwater Horizon Drilling Rig at Macondo Prospect**

**Inextinguishable Fire, Sinking two days later, leaving the well gushing at the seabed.**

# 1986. Chernobyl Nuclear Disaster

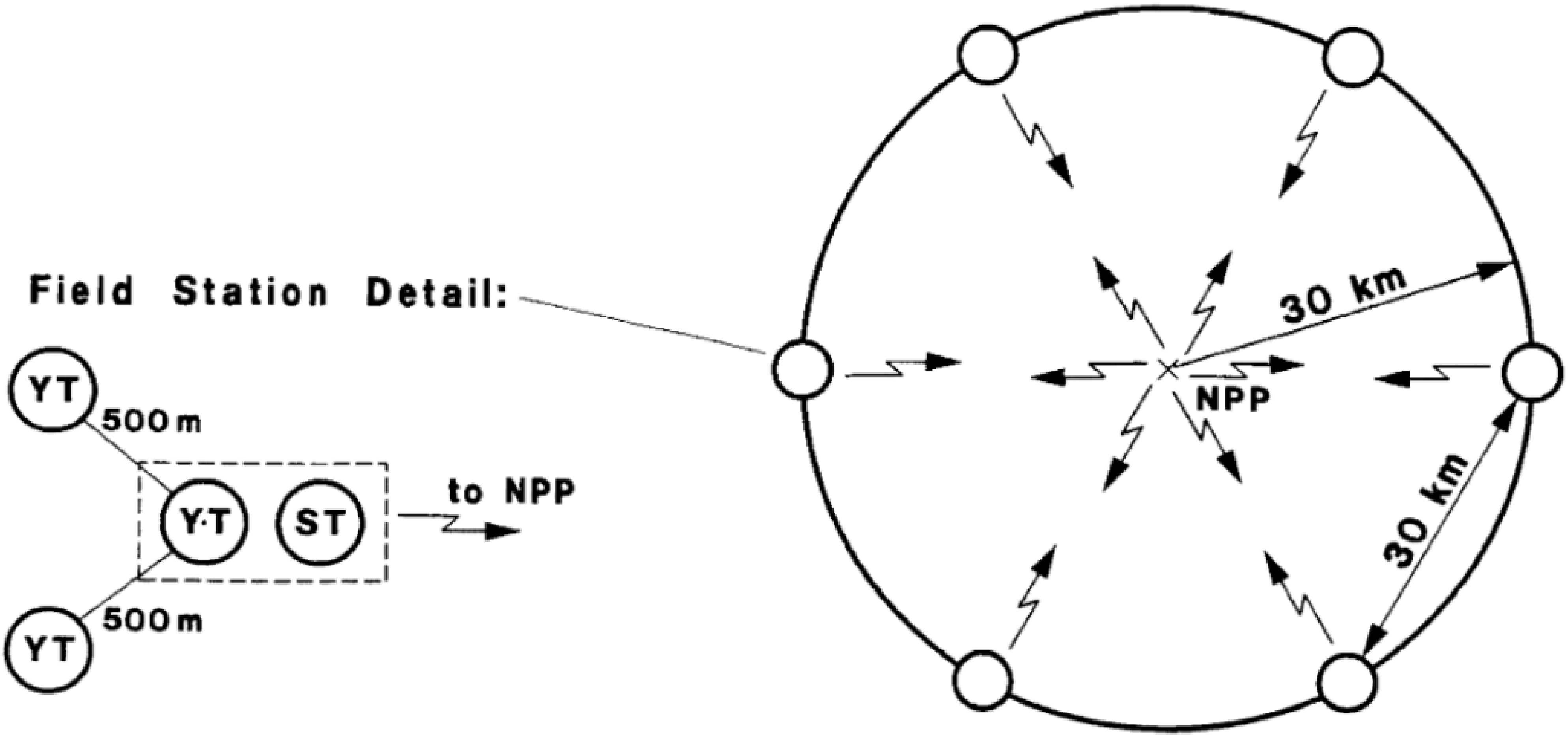
**Ukrainian Soviet Socialist Republic, Soviet Union**

**Reactor Safety Flaws and Human Actions**

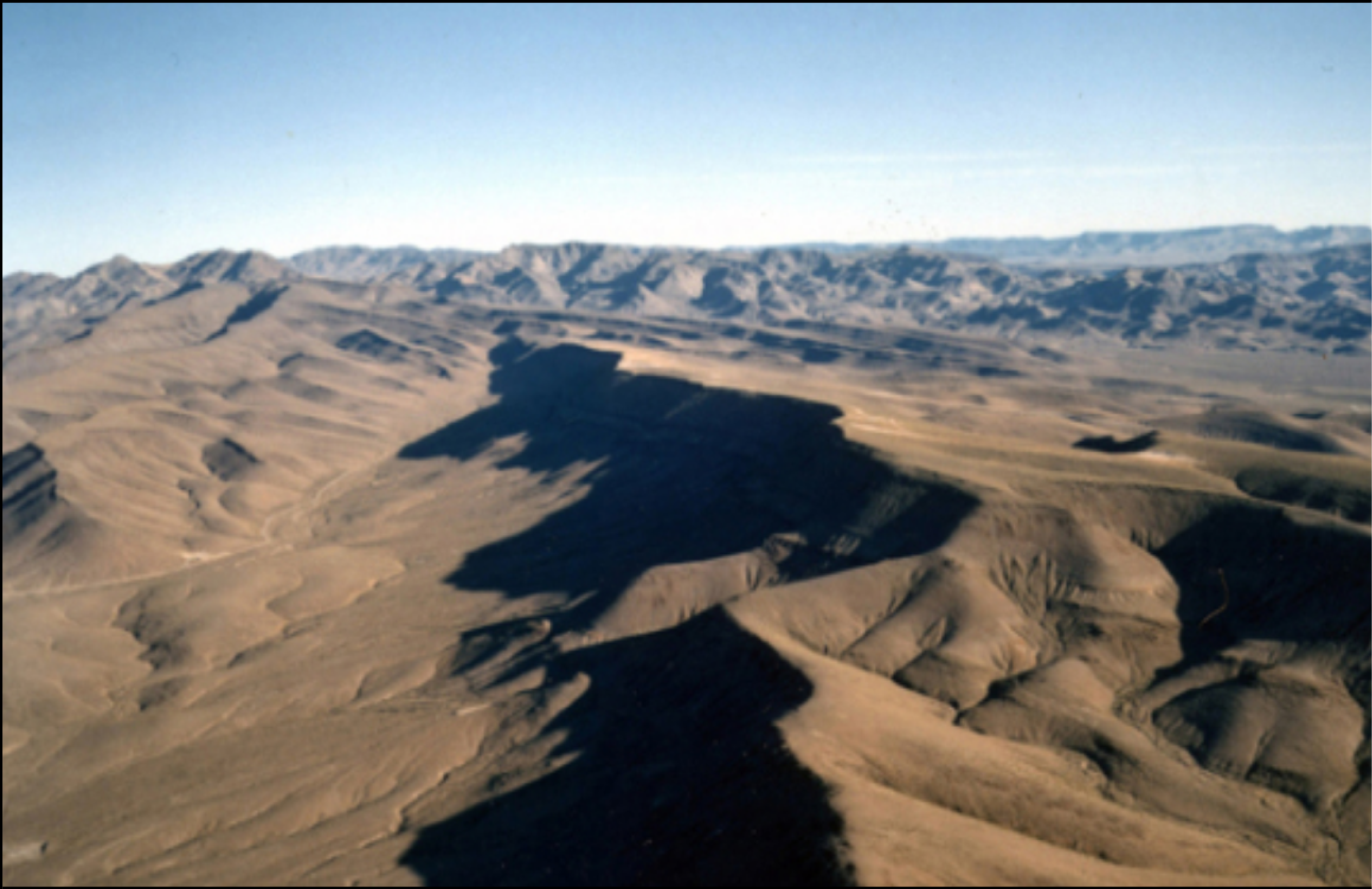
# Ignalina Nuclear Power Plant

**Similar to Chernobyl Nuclear Power Plant**

**2004, 2009 Closed two-unit RBMK-1500 Reactors**




Ignalina Nuclear Station Earthquake Early Warning



The Yucca Mountain Nuclear Waste Repository

The Yucca Mountain Nuclear Waste Repository

# Hanford Radioactive Containment Site

**Hanford site represents two-thirds of the nation's high level radioactive waste by volume**


Hanford Radioactive Containment Site


**Waste Isolation Pilot Plant, New Mexico, United States**

**Radioactive Containment Casks arriving at WIPP**

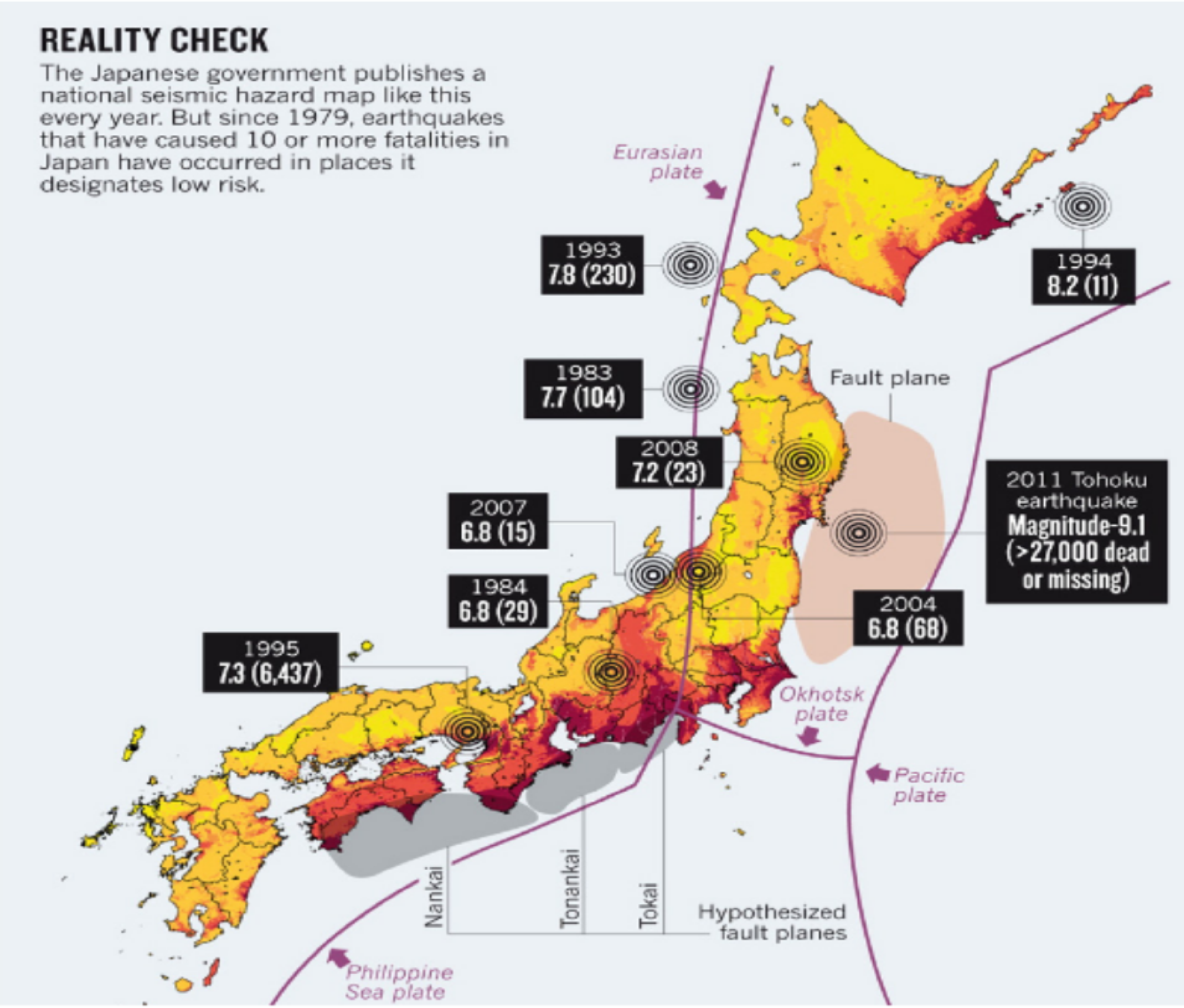

# Waste Isolation Pilot Plant

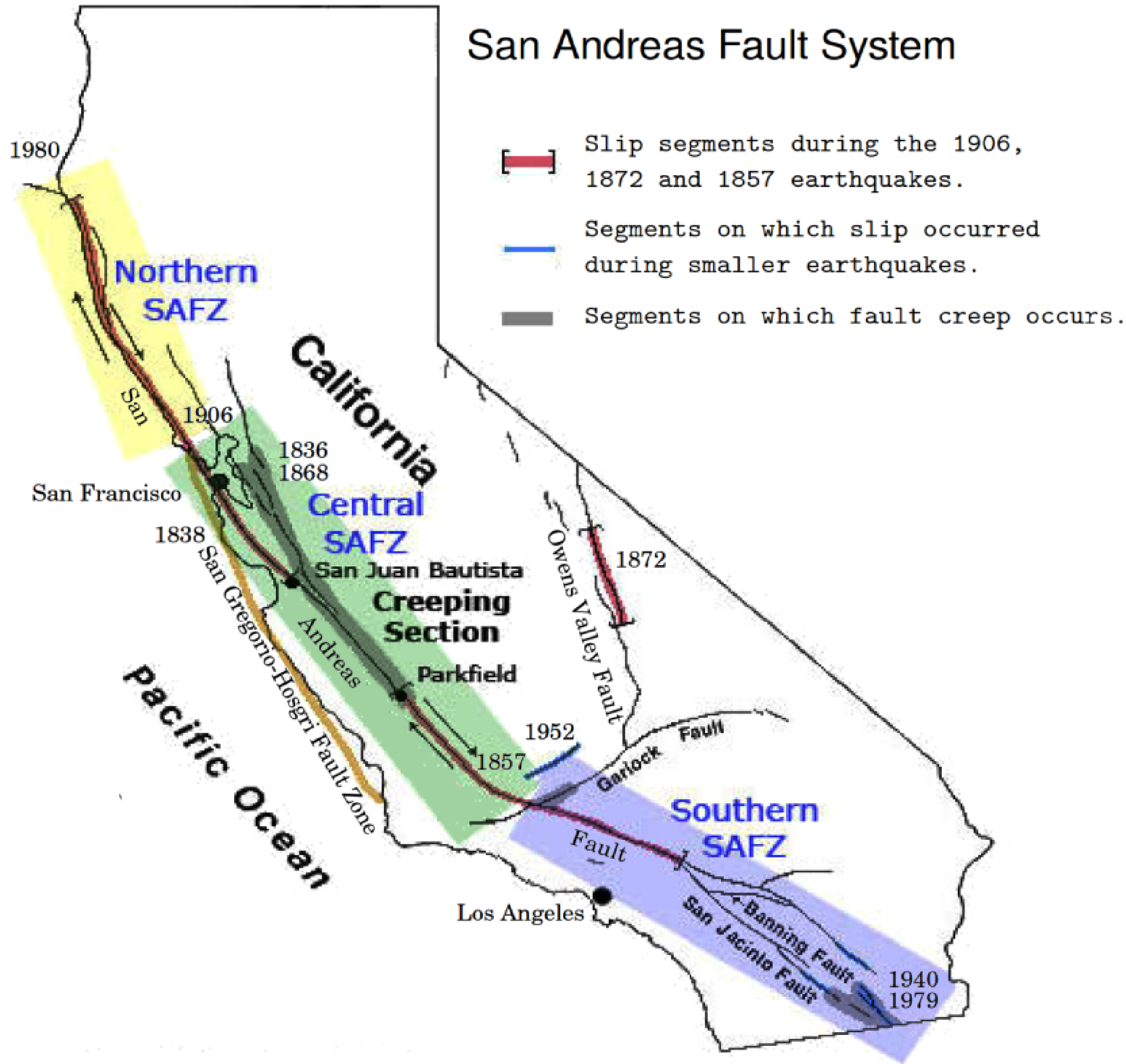
Radioactive Waste is placed in Rooms Underground

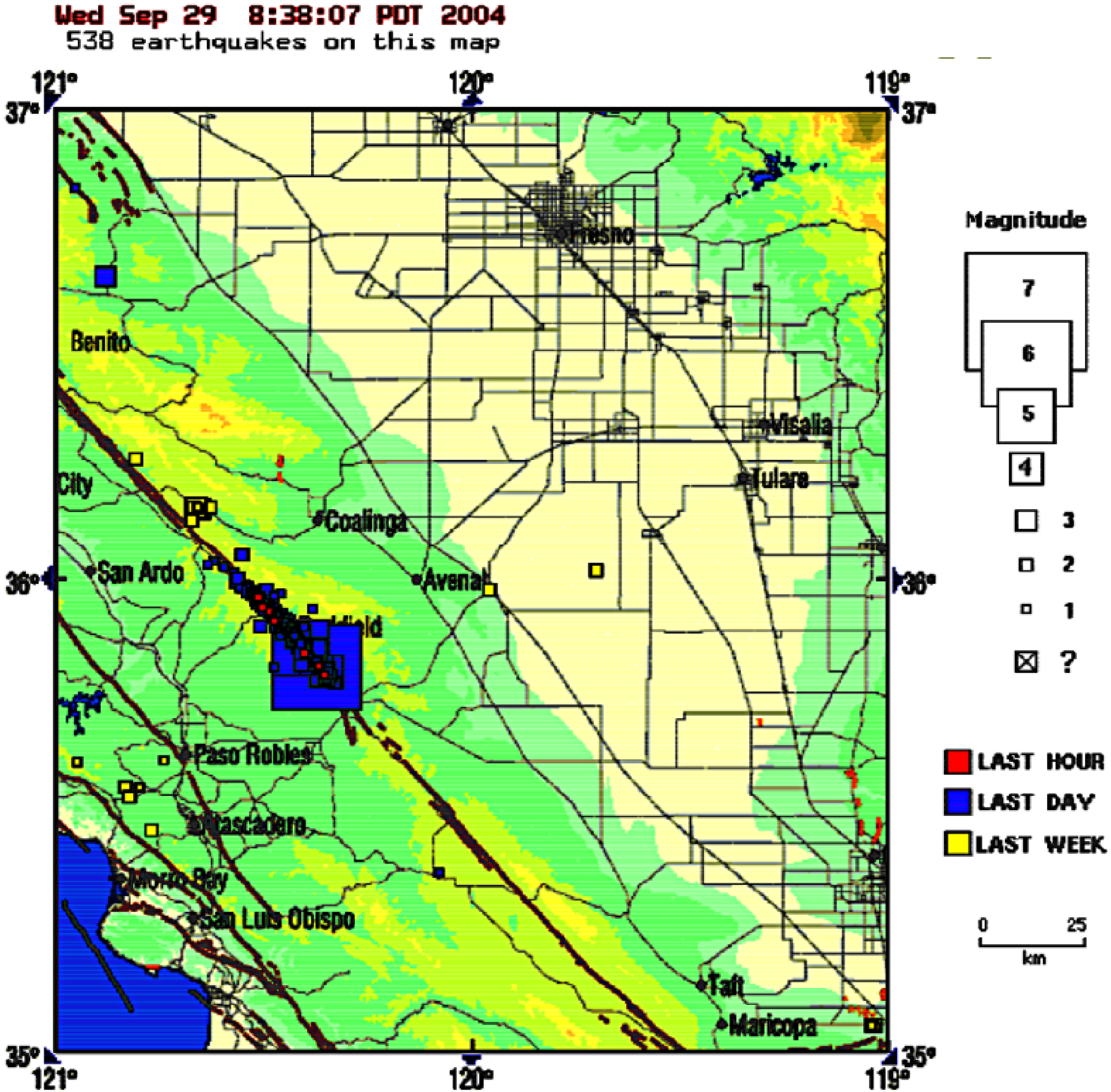
Waste Isolation Pilot Plant, New Mexico, United States

2014. Radioactive Leaks from Damaged Storage Drum

Waste Explosion, Airborne Release of Radiological Material


REALITY CHECK
The Japanese government publishes a national seismic hazard map like this every year. But since 1979, earthquakes that have caused 10 or more fatalities in Japan have occurred in places it designates low risk.
Eurasian plate
1993
7.8 (230)
1994
8.2 (11)
1983
7.7 (104)
Fault plane
2008
7.2 (23)
2011 Tohoku earthquake
Magnitude-9.1
(>27,000 dead or missing)
2007
6.8 (15)
1984
6.8 (29)
2004
6.8 (68)
1995
7.3 (6,437)
Okhotsk plate
Pacific plate
Nankai
Tonankai
Tokai
Hypothesized fault planes
Philippine Sea plate

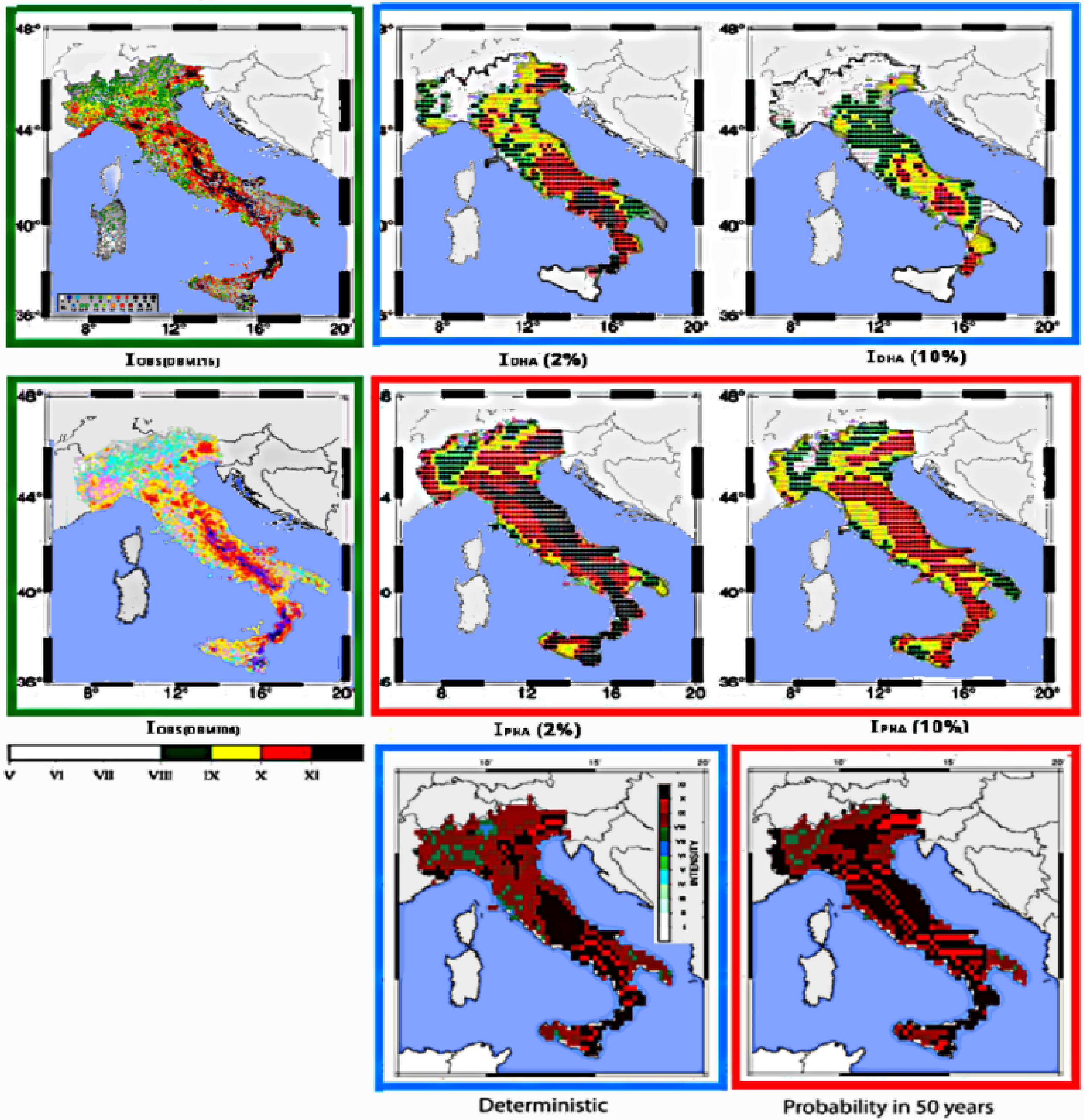

San Andreas Fault System
Slip segments during the 1906, 1872 and 1857 earthquakes.
Segments on which slip occurred during smaller earthquakes.
Segments on which fault creep occurs.
1980
Northern SAFZ
San
1906
California
1836
1868
San Francisco
Central SAFZ
1838
San Gregorio-Hosgri Fault Zone
San Juan Bautista
Creeping Section
Andreas
Parkfield
Owens Valley Fault
1872
Pacific Ocean
1952
1857
Garlock Fault
Southern SAFZ
Fault
Los Angeles
Banning Fault
San Jacinto Fault
1940
1979

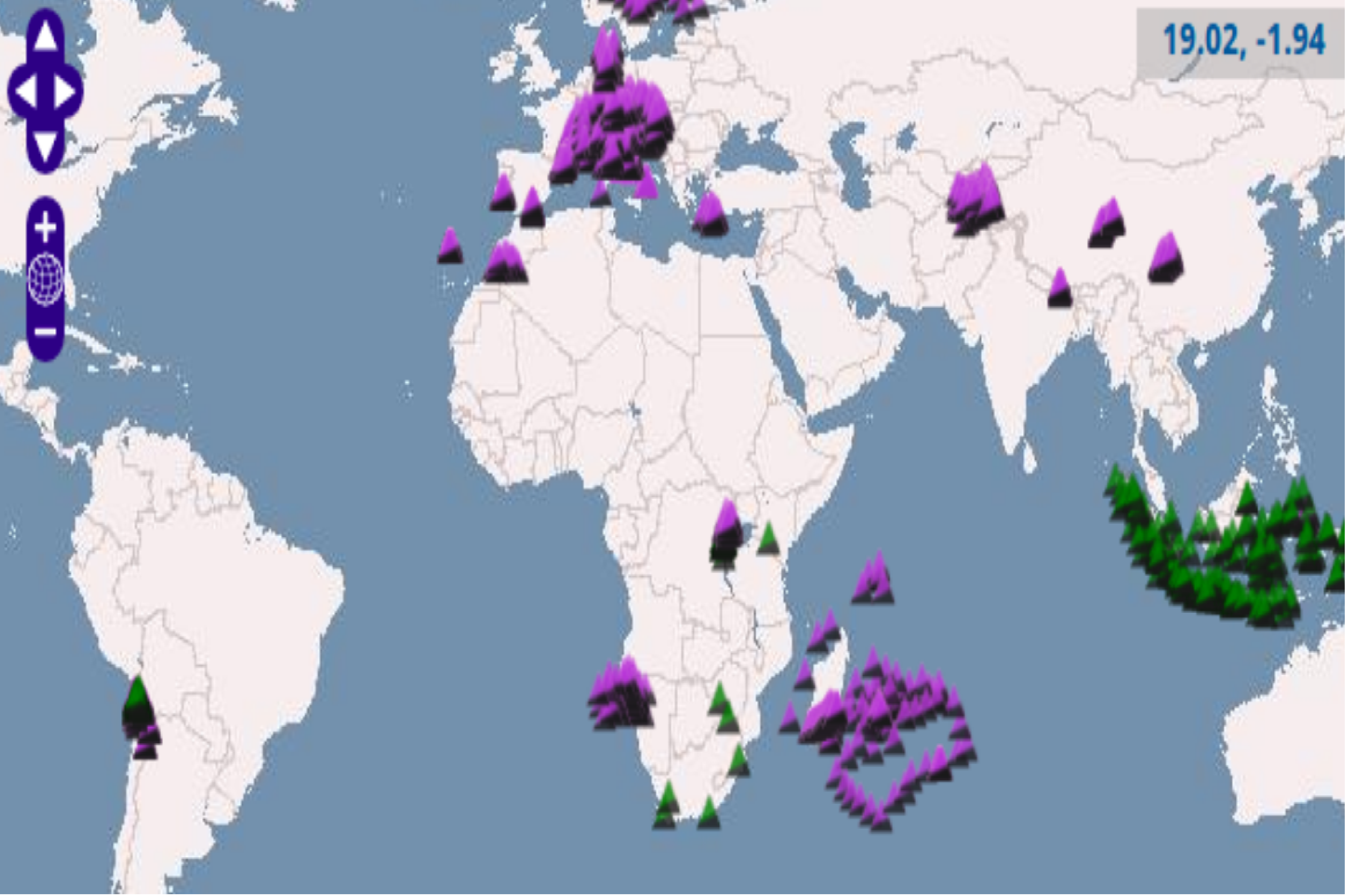


Wed Sep 29 8:38:07 PDT 2004
538 earthquakes on this map
121°
120°
119°
37°
36°
35°
Fresno
Benito
Visalia
Tulare
City
Coalinga
San Ardo
Avenal
Paso Robles
Atascadero
Morro Bay
San Luis Obispo
Taft
Maricopa
Magnitude
7
6
5
4
3
2
1
?
LAST HOUR
LAST DAY
LAST WEEK
0
25
km

## Italian Seismicity

## Overprediction of hazard risk levels






**Legend for Map icons** **Stations** Restricted and permanent Restricted and temporary

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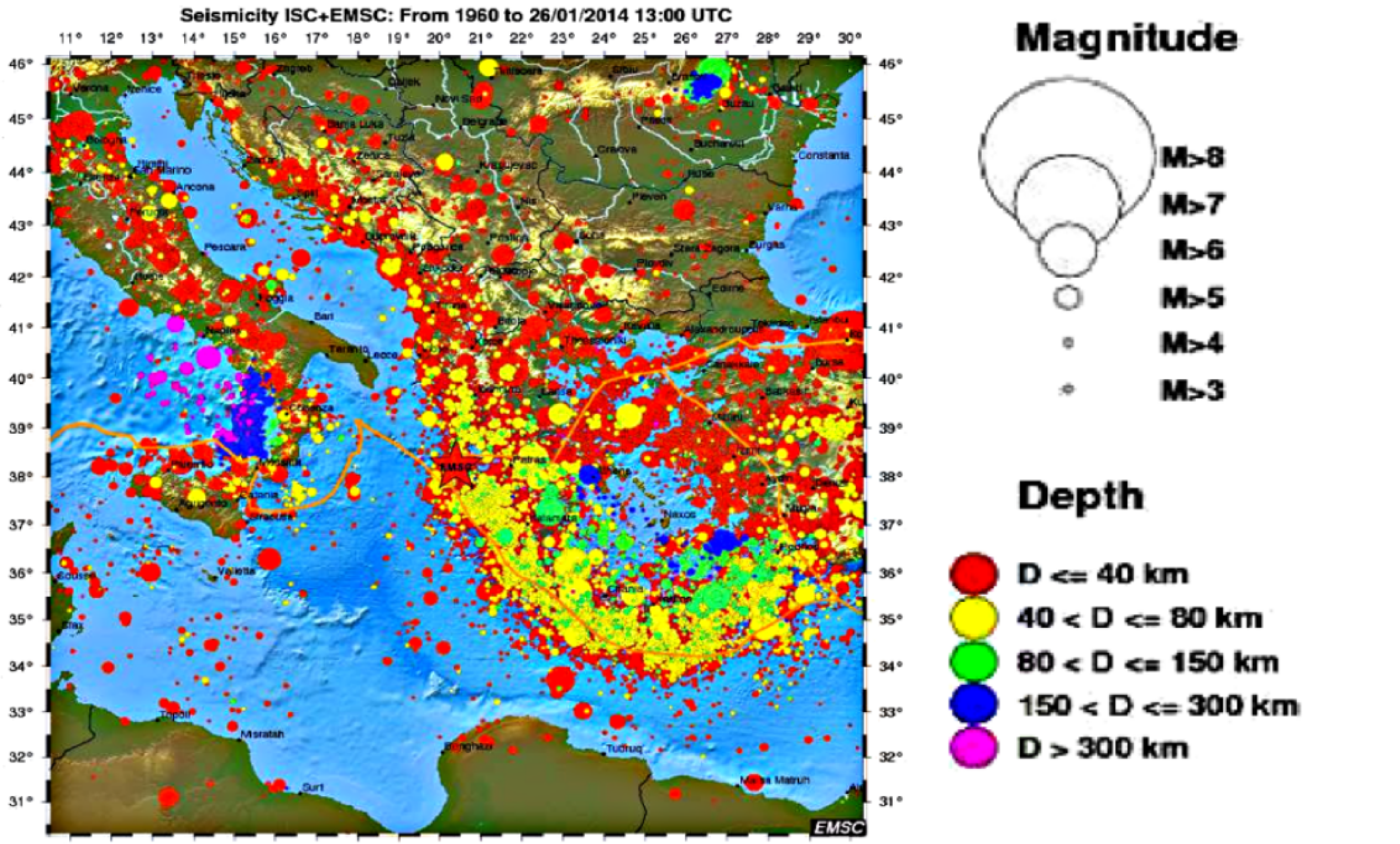
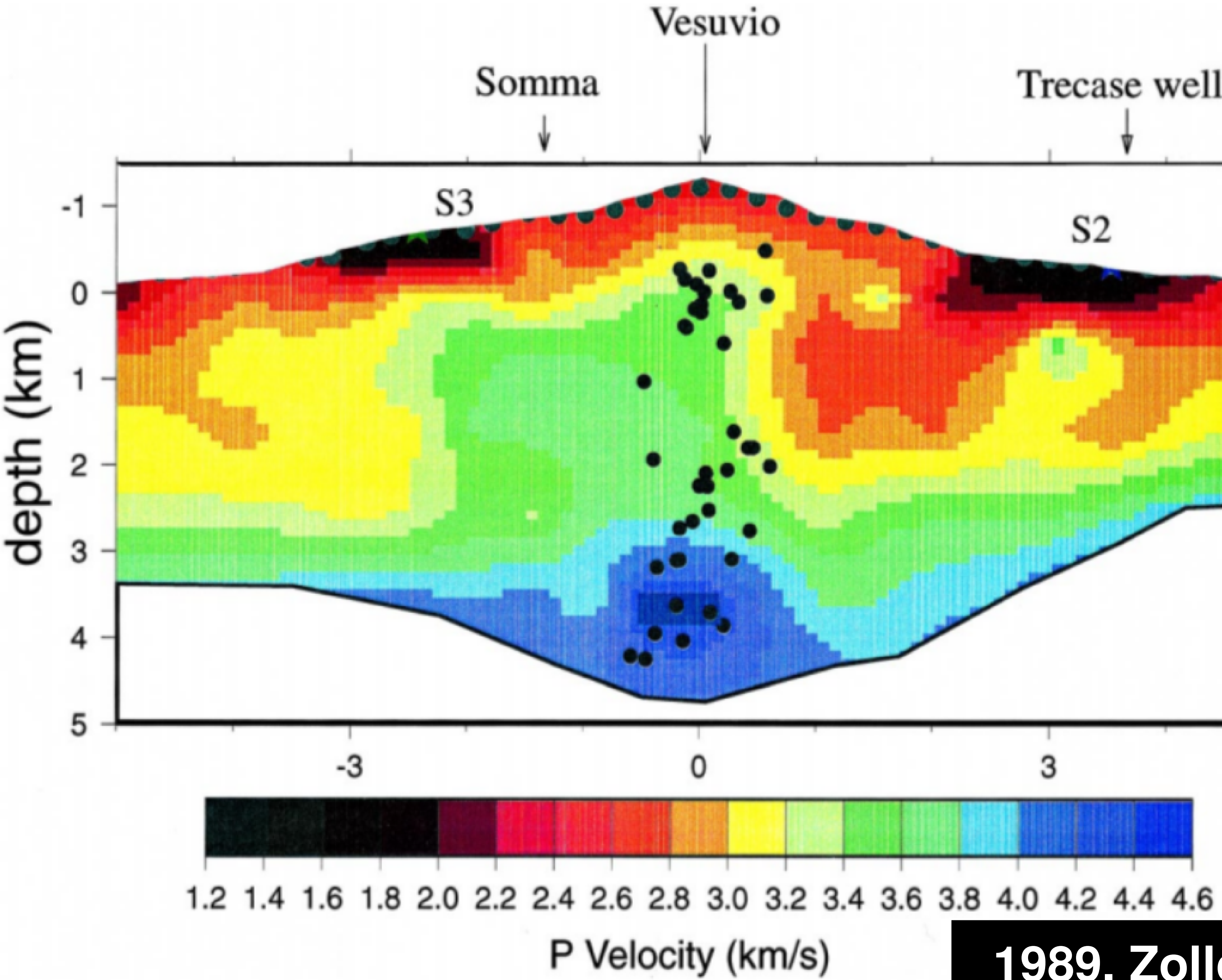
# 3. Seismic Subsurface Mapping

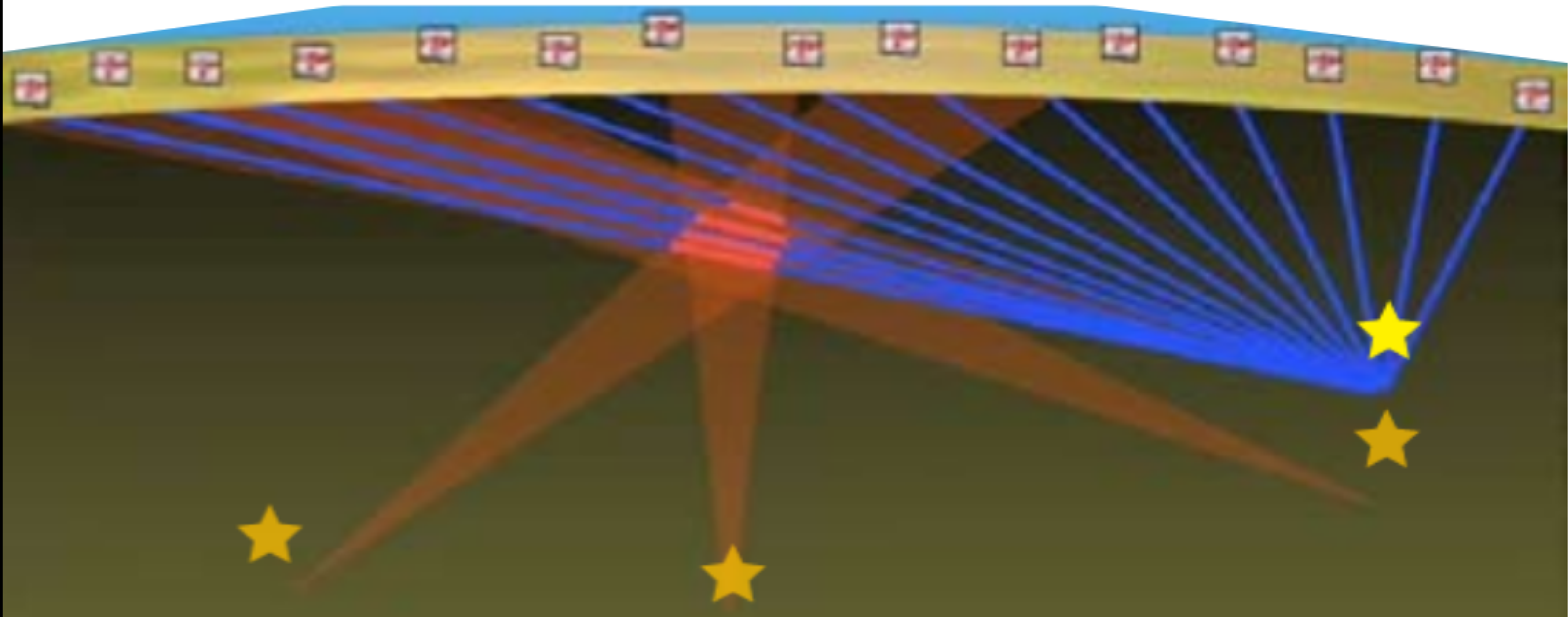



**European Mediterranean Seismological Centre**

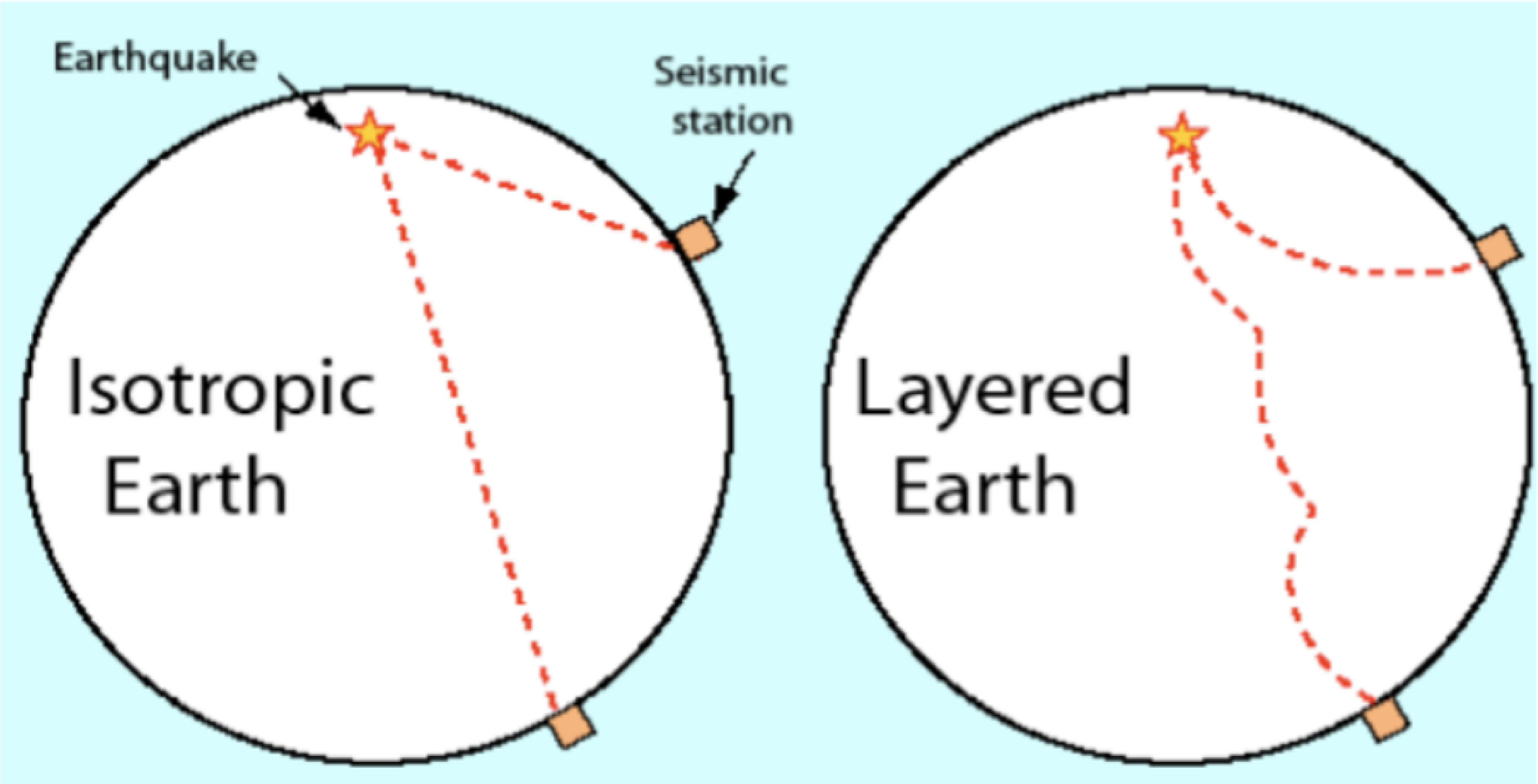
**İnduced Seismicity Consortium**

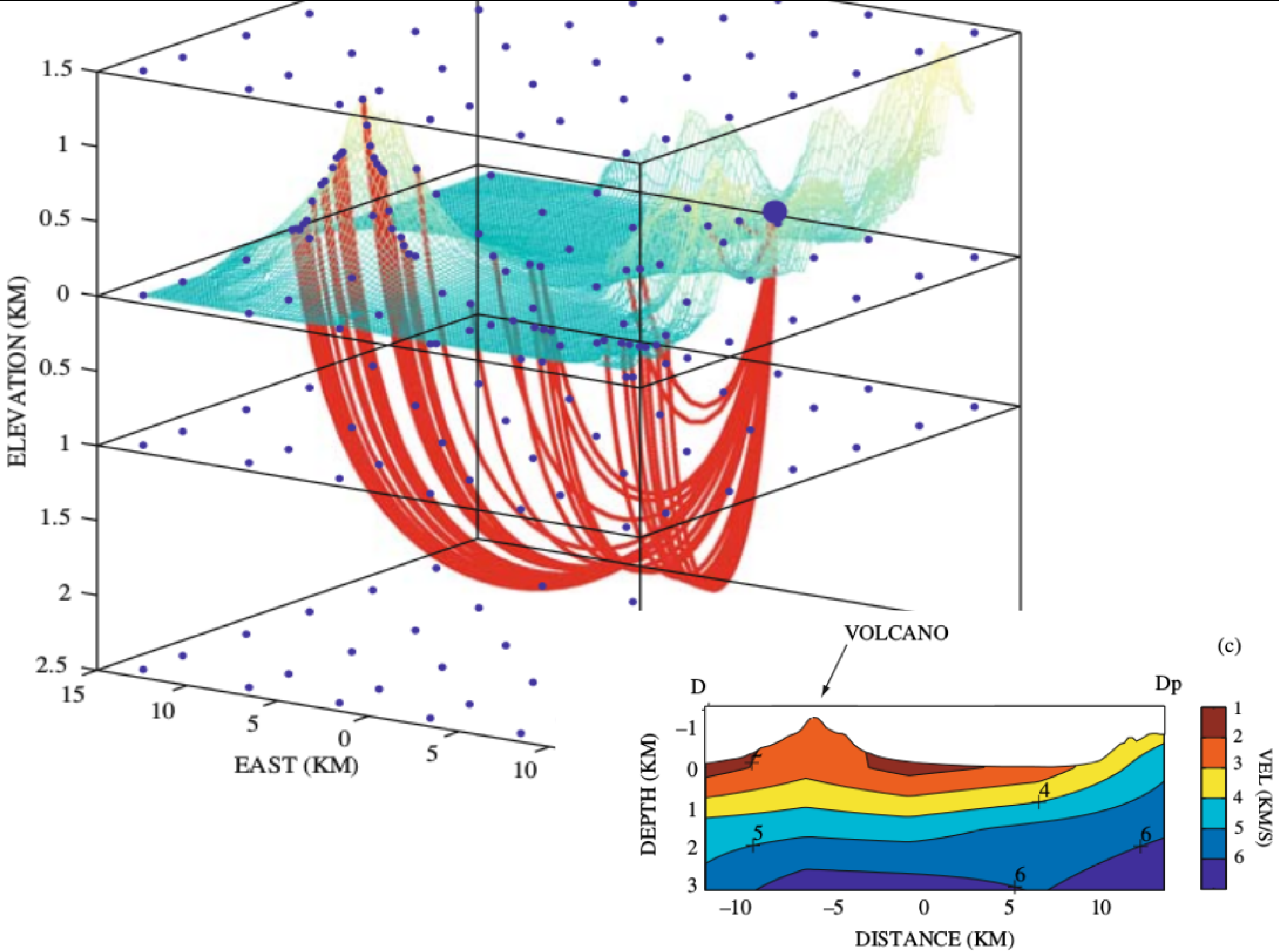



**1989. Zollo et al.**

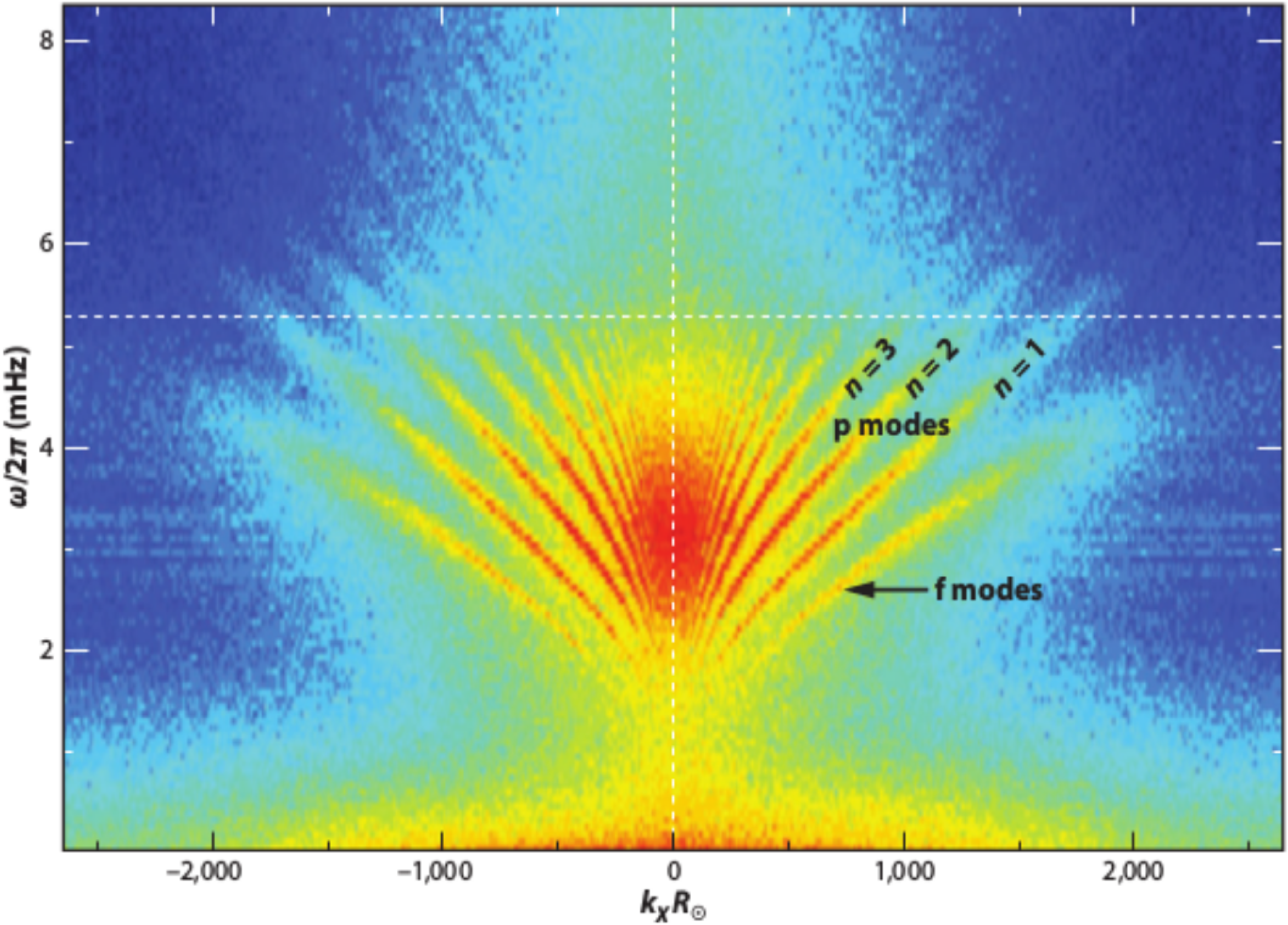


Slower region indicates different material than
the surroundings, and is often termed "an anomaly."


Earthquake
Seismic station
Isotropic Earth
Layered Earth



ELEVATION (KM)
1.5
1
0.5
0
0.5
1
1.5
2
2.5
15
10
5
0
5
10
EAST (KM)
VOLCANO
(c)
D
Dp
DEPTH (KM)
−1
0
1
2
3
4
5
6
6
−10
−5
0
5
10
DISTANCE (KM)
VEL (KM/S)
1
2
3
4
5
6



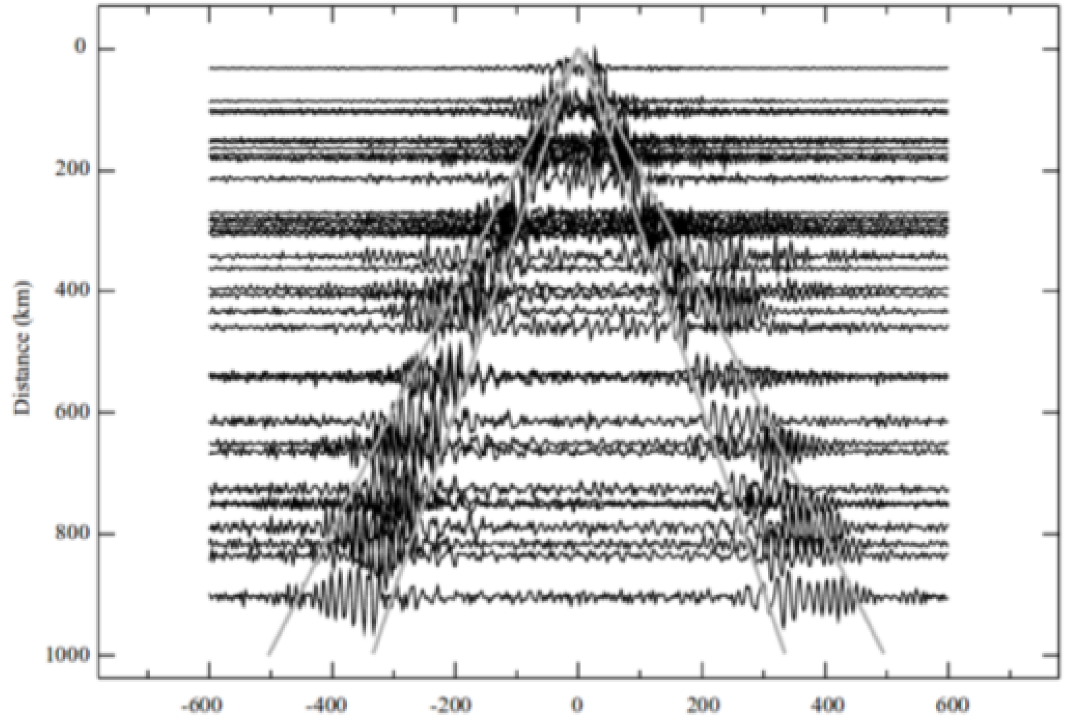
n = 3
n = 2
n = 1
p modes
f modes
8
6
4
2
ω/2π (mHz)
–2,000
–1,000
0
1,000
2,000
$k_x R_\odot$

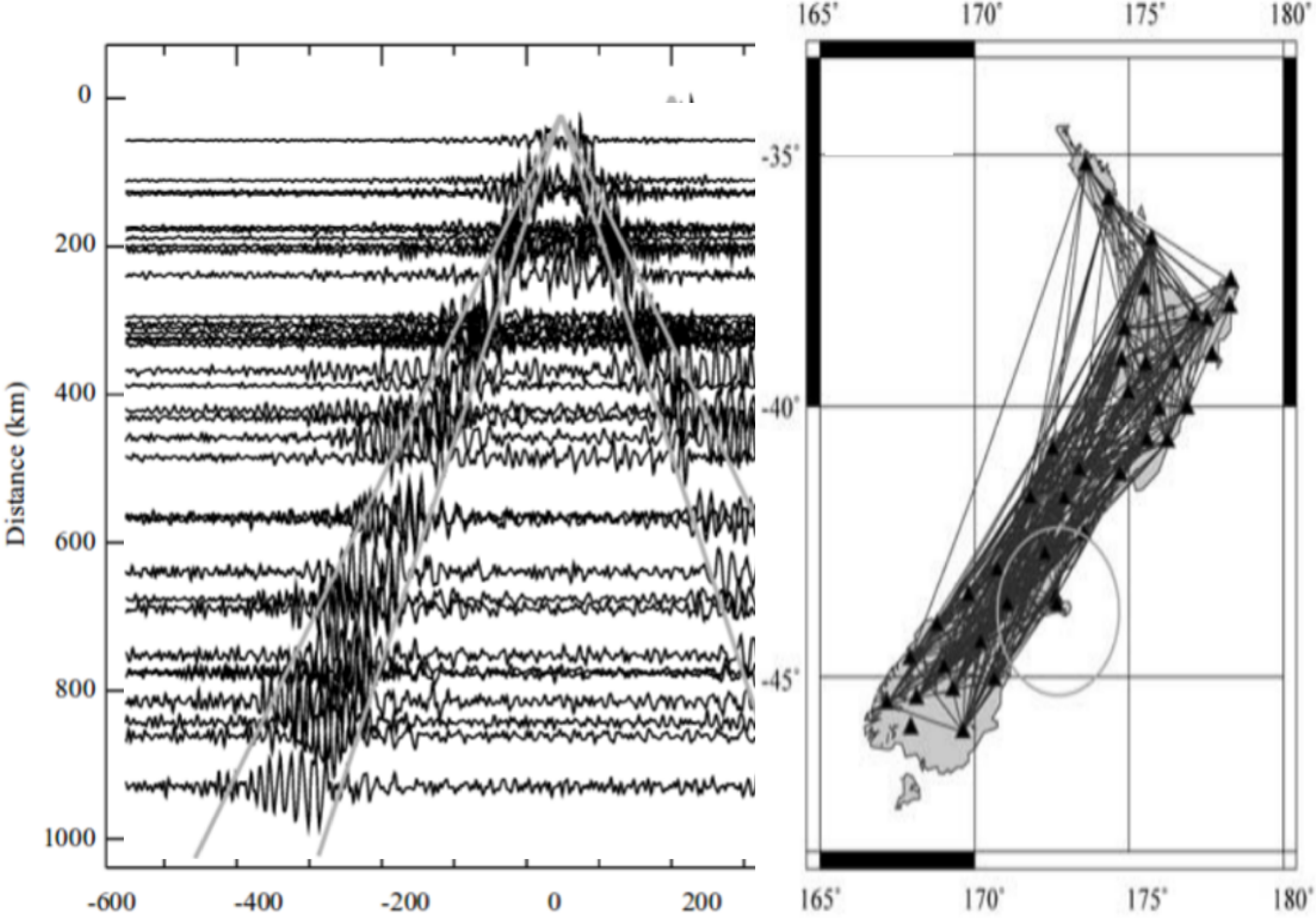
## 3.2. The Cross-Covariance Function

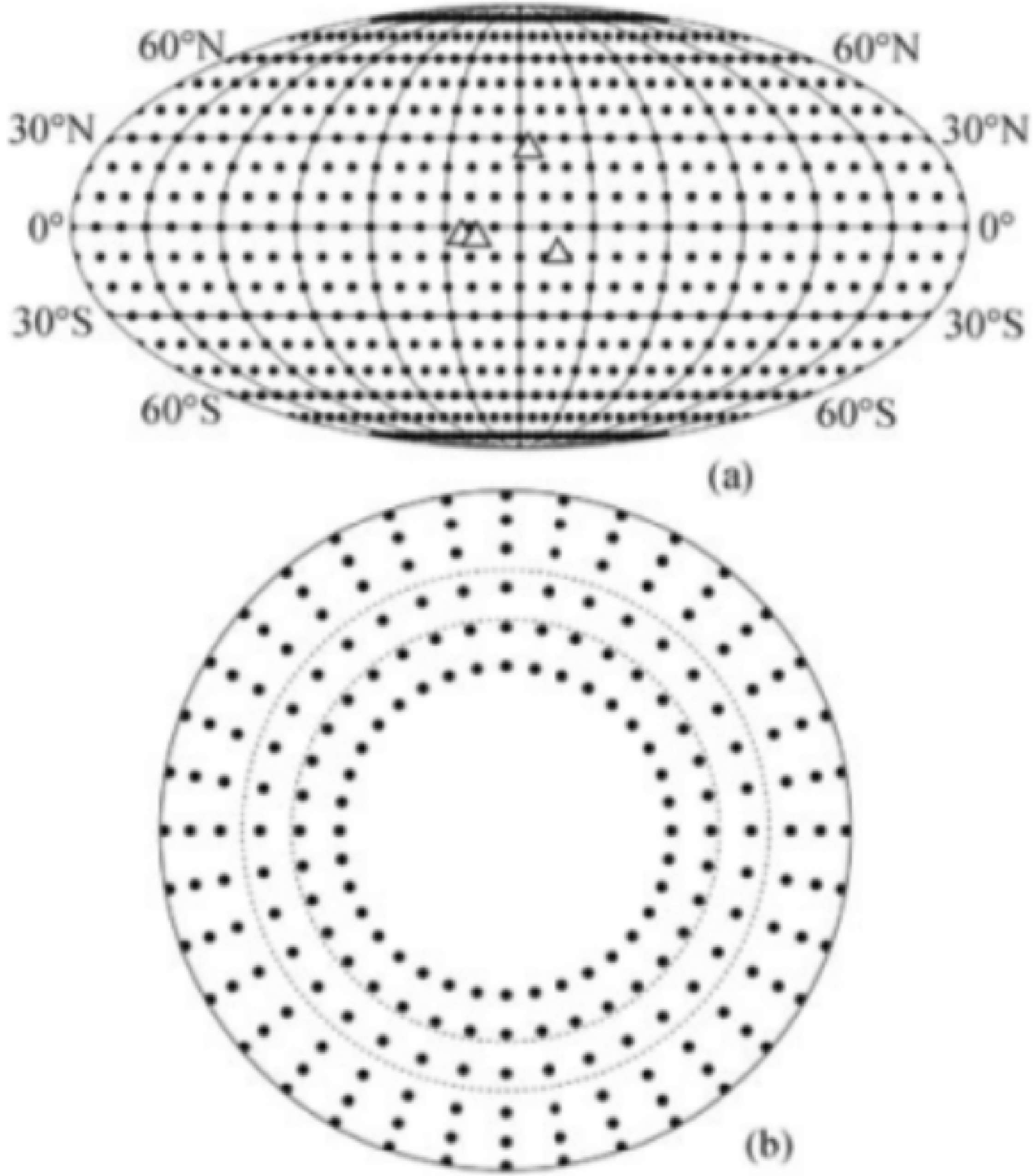
Time-distance helioseismology is based on the measurement of the cross-covariance between the Doppler signals at two points $\mathbf{r}_1$ and $\mathbf{r}_2$ on the solar surface,

$$C(\mathbf{r}_1, \mathbf{r}_2, t) = \int_0^T \mathrm{d}t' \, \phi(\mathbf{r}_1, t')\phi(\mathbf{r}_2, t' + t), \tag{5}$$

where $t$ is the correlation time lag. **Figure 6*a*** shows a cross-covariance function measured from 144 days of MDI medium-degree data. The cross-covariance has been averaged over many pairs of points ($\mathbf{r}_2$, $\mathbf{r}_1$) and is presented as a function of the heliocentric angle between these two points. This diagram is known as the time-distance diagram. The cross-covariance is essentially a phase coherent average of the random oscillations (Bogdan 1997, and **Supplemental Video 2**). It is a solar seismogram: it provides a way to measure wave travel times between two surface locations.




Distance (km)
0
200
400
600
800
1000
-600
-400
-200
0
200
165°
170°
175°
180°
-35°
-40°
-45°



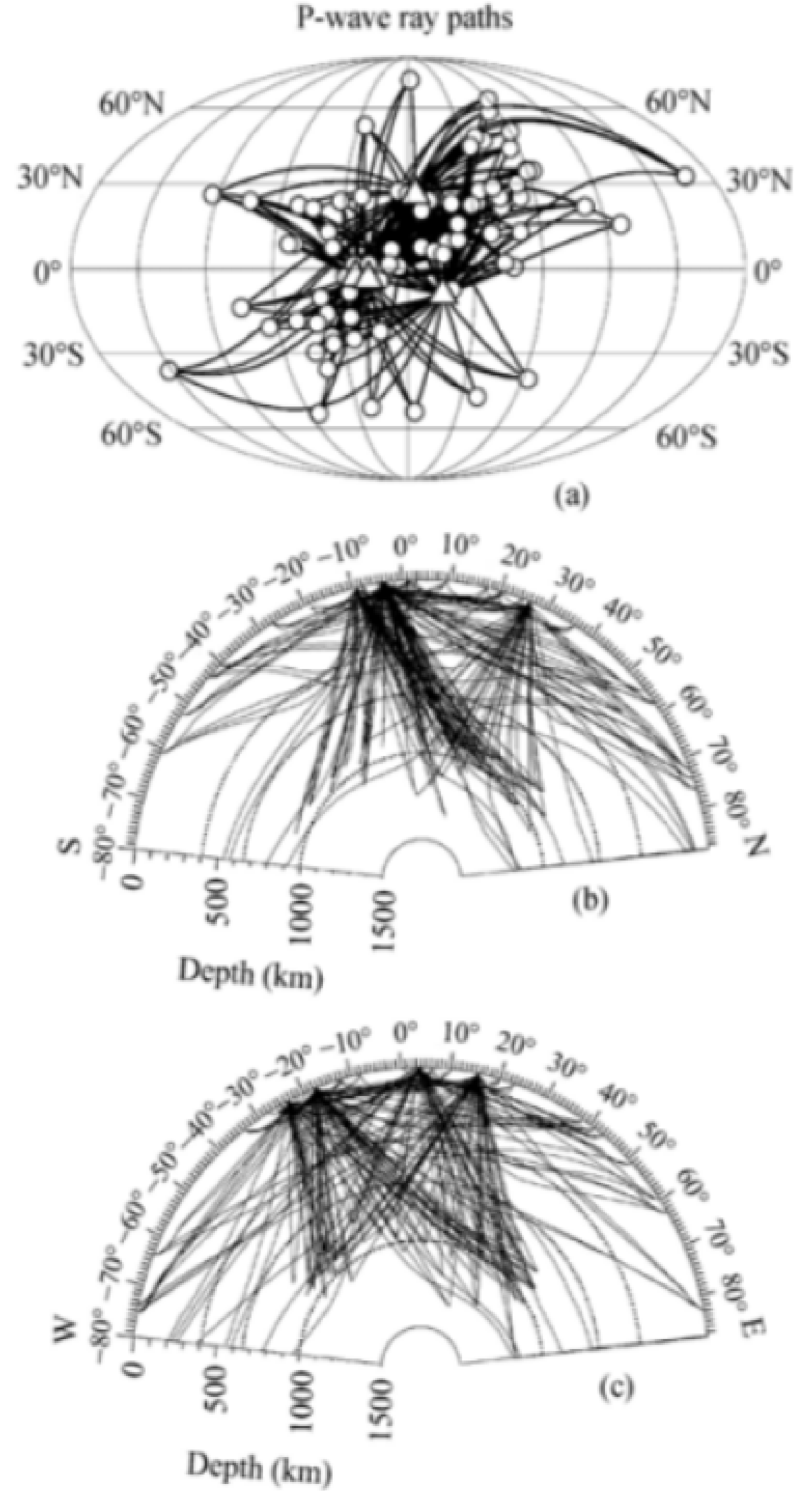
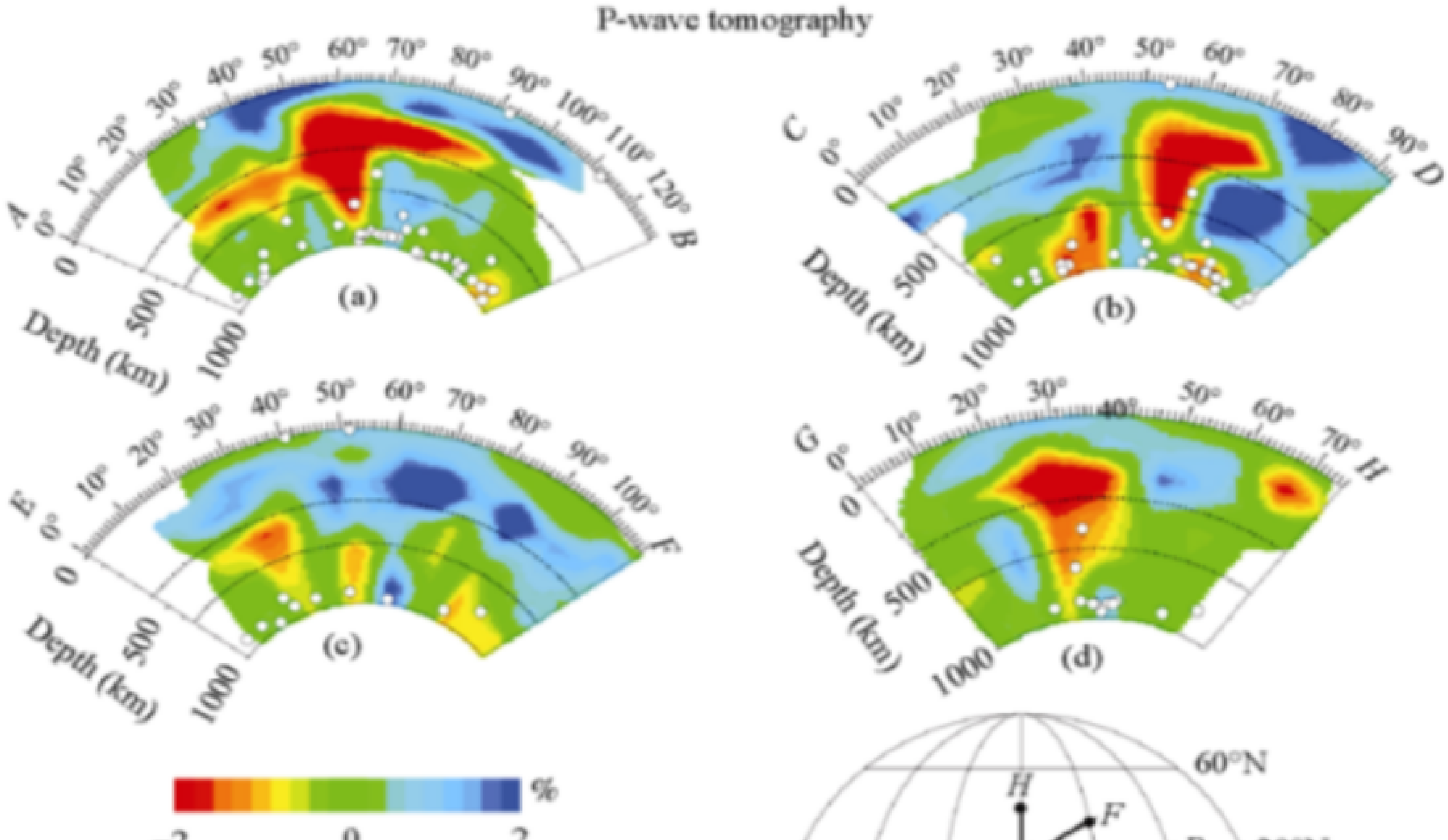




**Figure 4** Distribution of the grid nodes adopted for the tomogra inversion in plan view (a) and vertical cross section (b). The open tr gles in (a) denote the four Apollo seismic stations.



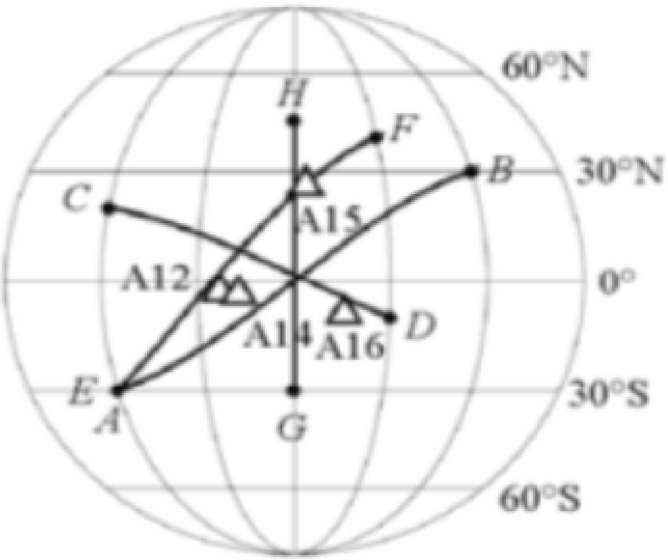
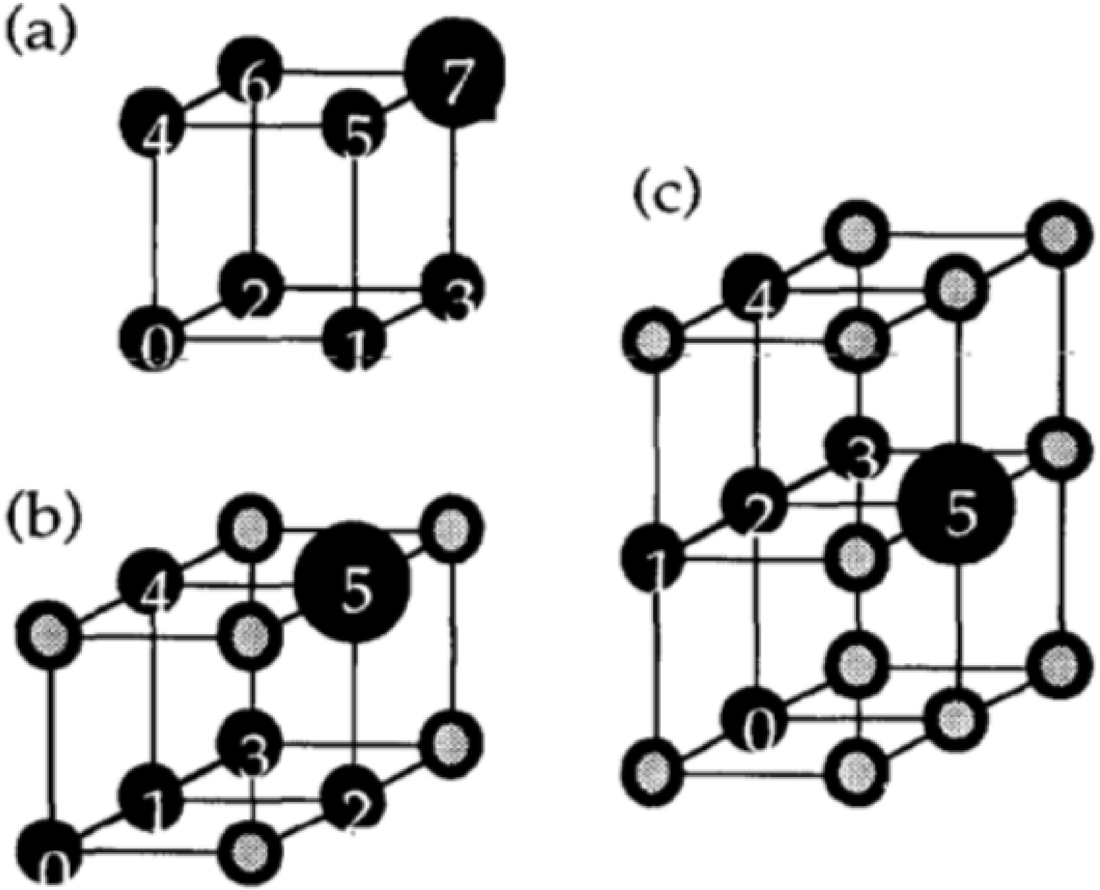




**Figure 9** Vertical cross sections of P-wave tomography along the four profiles shown on the map. Red and blue colors denote low and high velocities, respectively. The scale of velocity perturbations relative to the 1-D velocity model (Figure 3) is shown below (c). White dots denote moonquakes occurring within 150 km width of each profile. Open triangles on the map denote the four Apollo seismic stations.




$$\left(\frac{\partial t}{\partial x}\right)^2 + \left(\frac{\partial t}{\partial y}\right)^2 + \left(\frac{\partial t}{\partial z}\right)^2 = s^2(x, y, z)$$

$$t_7 = t_0 + \frac{1}{\sqrt{2}}\sqrt{6h^2s^2 - (t_1 - t_2)^2 - (t_2 - t_4)^2 - (t_4 - t_1)^2 - (t_3 - t_5)^2 - (t_5 - t_6)^2 - (t_6 - t_3)^2}, \qquad (2)$$

$$t_5 = t_1 + \sqrt{2h^2s^2 - 0.5(t_0 - t_3)^2 - (t_2 - t_4)^2}. \qquad (3)$$

$$t_5 = t_2 + \sqrt{h^2s^2 - 0.25[(t_1 - t_3)^2 + (t_0 - t_4)^2]}.$$

**1990. Vidale**

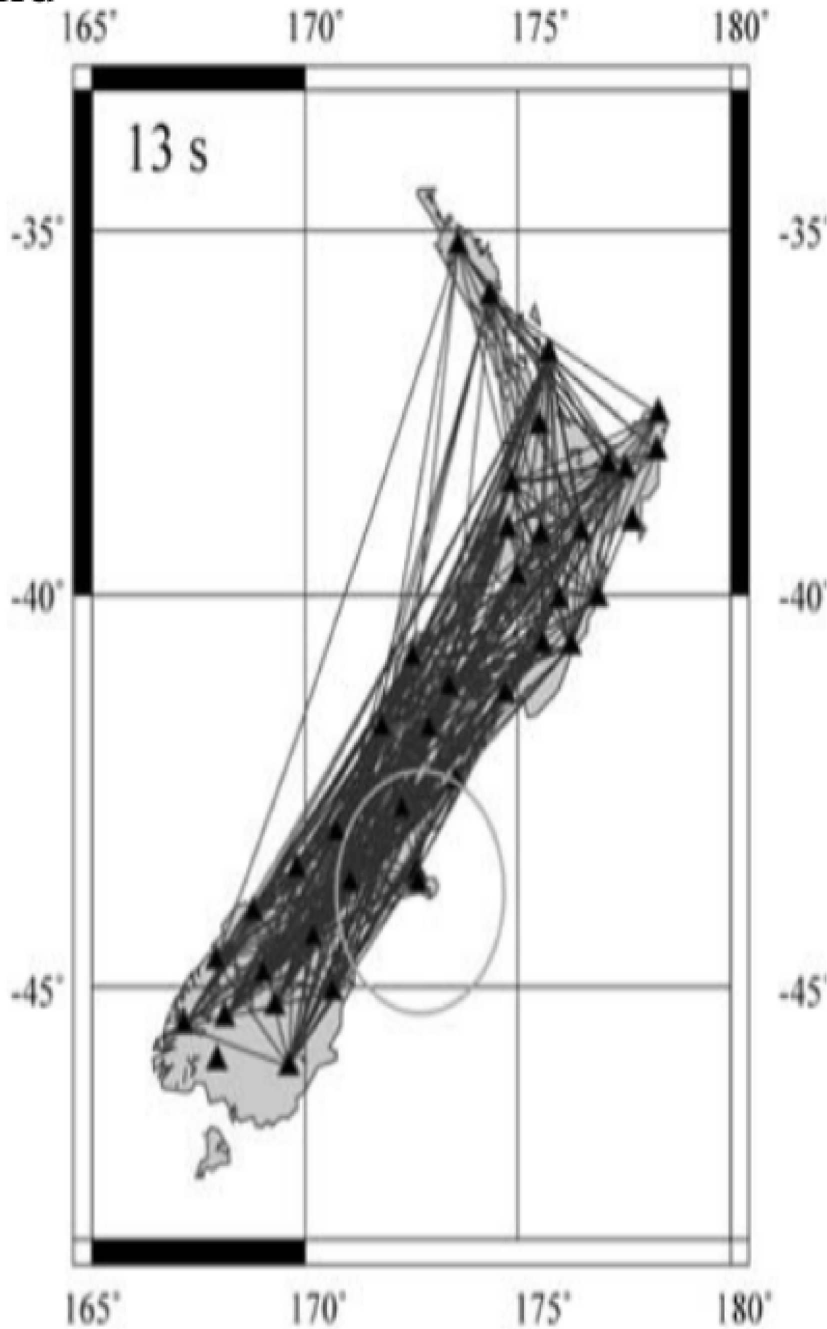
# Seismic Data: Earthquakes, Anthropogenic, Background

The current velocity distribution is updated according to the vector computed, and the process is repeated until the Subsurface Map stabilizes.

The ray path from a source to the station is defined by following the steepest gradient in the time grid from the source. From the ray geometry of all source-receiver pairs the matrix describing the forward tomographic problem can be computed:

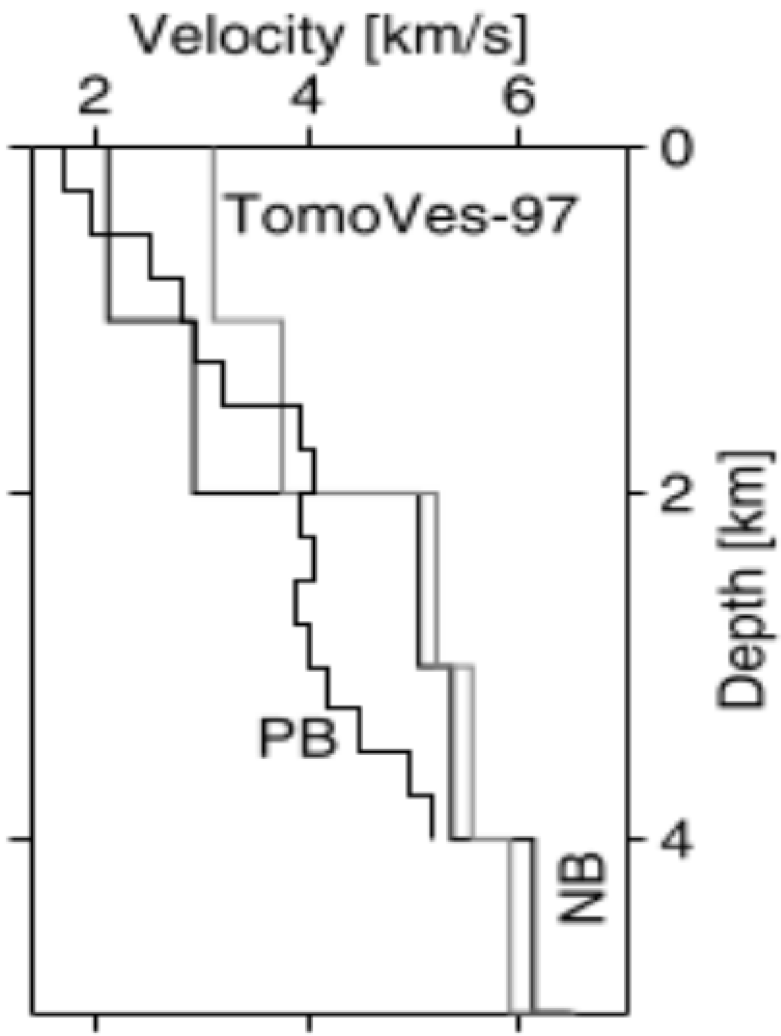
$$\mathbf{r} = \mathbf{G}\Delta u, \tag{1}$$

where $\mathbf{r}$ is the travel time residual vector, i.e., the difference between the observed travel times and the travel times computed in the current velocity distribution. $\Delta u$ is the slowness (1/velocity) perturbation vector. Each $G_{pj}$ coefficient is the length of the ray $p$ sampling cell $j$.



$$d_i = G_i(x_j)$$

Initial 3-D Velocity Distribution:
Starting Model designed using a subsurface simulation grid (nx, ny, nz)




To image a region we use an estimation grid of cubic cells describing the scale we want to resolve (mx, my, mz)

The current velocity distribution is updated according to the vector computed, and the process is repeated until the velocity model stabilizes.

We give a quick overview of the theory of systems of linear, algebraic equations. This is not intended to serve as a text on linear algebra, merely a review of some important concepts. Detailed discussions of various aspect of this material can be found in [43] or [78].

Consider a system of $m$ equations for $n$ unknowns, $(x_1, \ldots, x_n)$ :

$$\begin{aligned} a_{11}x_1 + a_{12}x_2 + & \cdots + a_{1n}x_n &= y_1 \\ a_{21}x_1 + a_{22}x_2 + & \cdots + a_{2n}x_n &= y_2 \\ \vdots \qquad & \qquad \vdots & \vdots \\ a_{m1}x_1 + a_{m2}x_2 + & \cdots + a_{mn}x_n &= y_m. \end{aligned} \tag{1.16}$$

There are four questions which require answers:

### 4.2.1 Inverse problem

The inverse problem corresponding to the forward problem given by 2 is nonlinear. We define the *a posteriori* probability density function (PDF) as

$$\sigma_M(m) = \exp\left(-\frac{1}{2}\left(\sum_{i=0}^{I-1}\left(\frac{g(m)_i - d_i^{\text{obs}}}{\sigma_i}\right)^2 + \sum_{j=0}^{N-1}\frac{S_j}{S}\left(\frac{c_j - c_j^{\text{prior}}}{\sigma_c}\right)^2 + \sum_{j=0}^{N-1}\frac{S_j}{S}\left(\frac{l_j - l_j^{\text{prior}}}{\sigma_l}\right)^2 + \sum_{k=0}^{M-1}\left(\frac{A_k - A_k^{\text{prior}}}{\sigma_A}\right)^2\right)\right) \tag{7}$$

Existence:

For a given $m$-vector $(y_1, \ldots, y_m)$ does there exist an $n$-vector $(x_1, \ldots, x_n)$ which satisfies the equations in (1.16)?

Uniqueness:

When a solution exists is it unique? More generally, describe the space of solutions.

Solve in practice:

Give an algorithm to find approximations for the solutions of (1.16) and criteria to select a solution when there is more than one.

Stability:

How sensitive is the solution to small variations in the coefficients $(a_{ij})$ or the right hand side $(y_j)$?

It is a somewhat unexpected, but very important fact that these issues are in practice, rather independent of one another.

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